FIXED ABRASIVE ARTICLES

The present application is a continuation-in-part application of United States Patent Application Serial Number 09/563,628, filed May 2, 2000, which claims priority to U.S. Provisional Patent Application No. 60/132,175, filed on May 3, 1999, the disclosures of each of which are incorporated herein by reference.

Field of the Invention

The invention relates to fixed abrasive articles for chemical mechanical polishing (CMP) and has particular applicability in manufacturing semiconductor devices.

Background

Abrasive articles are used in a variety of industrial applications for abrading, finishing, and polishing surfaces such as microelectronic devices (e.g., semiconductor devices) and magnetic recording media. Typical industrial uses of abrasive articles include polishing a substrate, as during various phases in manufacturing.

In manufacturing semiconductor devices, a wafer typically undergoes numerous processing steps, including deposition, patterning, and etching. After one or more of these processing steps it is necessary to achieve a high level of surface planarity and uniformity to enable accurate photolithographic processing. A conventional planarization technique comprises polishing, as by chemical mechanical polishing, "CMP," wherein a wafer carrier assembly is rotated in contact with a polishing pad in a CMP apparatus. The polishing pad is mounted on a rotating/moving turntable or platen. The wafers are mounted on a carrier or polishing head, and a controllable force presses the wafers against the rotating polishing pad. Thus, the CMP apparatus effects polishing or rubbing movement between the surface of a semiconductor wafer and the polishing pad. Optionally, a polishing slurry containing abrasive particles in a solution can be dispersed on the pad and wafer.

Some polishing pads used in abrasive slurry processing include a grooved porous polymeric surface, and the abrasive slurry can be chosen according to the particular material undergoing CMP. The abrasive slurry can be impregnated into the pores of the polymeric surface while the grooves convey the abrasive slurry to the wafer undergoing CMP. A polishing pad for use in CMP slurry processing is disclosed by Krywanczyk et al. in U.S. Patent 5,842,910. Typical CMP can be performed not only on a silicon wafer itself, but on various dielectric layers such as silicon oxide, conductive layers such as aluminum and copper, or a layer containing both conductive and dielectric materials, as in damascene processing.

A different type of abrasive article from the above-mentioned abrasive slurry-type polishing pad is a fixed abrasive article, e.g., fixed abrasive polishing sheet or pad. Such a fixed abrasive article typically comprises a backing with a number of abrasive composite elements adhered thereto. The abrasive composite elements may include abrasive particles in a binder, e.g., a polymeric binder. During CMP, the workpiece, e.g., wafer undergoing CMP wears away the fixed abrasive elements thereby exposing fresh abrasive particles. A chemical agent can be provided, e.g., in the working fluid or incorporated in the fixed abrasive article, to provide chemical activity, while the mechanical activity is provided by the fixed abrasive elements. Thus, such fixed abrasive articles do not require the use of a slurry containing loose abrasive particles and advantageously simplify effluent treatment, reduce the cost of consumables, and reduce dishing as compared to polishing pads that require an abrasive slurry. During CMP using a fixed abrasive polishing pad, a chemical agent can be applied to the pad, the agent depending on the particular material or materials undergoing CMP. However, the chemical agent does not necessarily contain abrasive particles as in abrasive slurry-type CMP operations. Fixed abrasive articles are disclosed by Rutherford et al. in U.S. Patent No. 5,692,950, Calhoun in U.S. Patent No. 5,820,450, Haas et al. in U.S. Patent No. 5,453,312, Hibbard et al. in U.S. Patent No. 5,454,844, Bruxvoort et al. in U.S. Patent No. 5,958,794, Kaisaki in WO 98/49723, and Ravipati et al. in U.S. Patent No. 5,014,468.

During CMP, the surface of conventional polymeric polishing pads for abrasive-slurry type CMP operations becomes glazed, thus nonreceptive to accommodating and/or dispensing the abrasive slurry, and otherwise incapable of polishing at a satisfactory rate and uniformity. Accordingly, conventional practices comprise periodically conditioning the pad surface so that it is maintained in a proper form for CMP. Conventional conditioning means comprises a diamond or silicon carbide (SiC) conditioning disk to condition the polishing pad. After repeated conditioning operations, the pad is eventually consumed and incapable of polishing at a satisfactory rate and uniformity. At this point, the polishing pad must be replaced. During replacement, the CMP apparatus is unavailable for polishing with an attendant significant decrease in production throughput.

There exists a need to extend the useful life of a fixed abrasive article while simultaneously maintaining high wafer-to-wafer rate stability. There also exists a need for a CMP apparatus enabling the use of fixed abrasive polishing pads having an extended life and achieving high wafer-to-wafer rate stability. There also exists a need for fixed abrasive articles, methods of manufacturing fixed abrasive articles, CMP apparatus employing fixed abrasive articles and CMP methods using fixed abrasive articles which: enable a reduction in contamination during CMP; improve CMP as by facilitating web removal; avoid formation of air bubbles under a fixed abrasive web; facilitate application of chemicals during CMP; allow tailoring of a fixed abrasive article for use to process a variety of substrate materials; reduce and/or eliminating indexing; dissipate heat during CMP; improve conformance of the polishing web during CMP; condition a fixed abrasive element; increase the amount of web material stored on a roll; monitor CMP; optimize the use of chemicals during CMP; optimize controlling CMP temperature; tailor the chemical agent during CMP; reduce particulates in the CMP effluent; detect and analyze effluent particles to determine their composition; control the particles in the effluent to reduce scratching and dishing; determine the useful lifetime of fixed abrasive elements during CMP; optimize the lifetime of a fixed abrasive article; optimize indexing; and generally improve the efficiency, increasing manufacturing throughput and reducing cost of CMP.

Summary of the Invention

The present invention relates to methods and fixed abrasive articles that incorporate a wear indicator. The methods and articles allow a user to monitor and determine the useful lifetime and the end of the useful lifetime of fixed abrasive articles, and to optimize, e.g., maximize, the actual amount of use of the fixed abrasive article.

As a fixed abrasive article works against a substrate, to abrade or polish, etc., abrasive composite elements are abraded and wear down over time. According to the invention, the abrasion of the abrasive composite elements causes a change of a feature or property of the fixed abrasive article or its interaction with the substrate. Monitoring the fixed abrasive article or the process to detect that change allows an objective basis for identifying an optimal point in the lifetime of a fixed abrasive article to replace that fixed abrasive article.

Normally in processing substrates with a fixed abrasive article, the fixed abrasive article must be stopped and examined to determine whether the abrasive article should be replaced with a fresh abrasive article. These interruptions are inefficient and can be avoided by using methods and fixed abrasive articles of the invention. And while the replacement of worn fixed abrasive articles can cause inefficiencies and down-time, neglecting to replace a worn abrasive article presents the possibility of damaging substrates being processed. On the other hand, to replace the abrasive article prematurely, at a time when the abrasive article still has significant useful life, causes inefficiencies and increases processing costs due not only to the cost of failing to fully use the abrasive article, but also by unnecessarily causing additional down-time during excessive replacements. The present invention allows for optimal use of a fixed abrasive article and minimizes the number of times fixed abrasive articles need to be replaced during processing.

An aspect of the invention relates to a fixed abrasive article comprising a three-dimensional abrasive composite in the form of abrasive composite elements, and further comprising a wear indicator.

Another aspect of the invention relates to a fixed abrasive article comprising posts having an inert chemical or mechanical indication to indicate post consumption.

Throughout this application, the following definitions apply:

An "abrasive agglomerate" refers to a plurality of abrasive particles bonded together in the form of a unitary particulate mass.

An "abrasive composite element" refers to one of a plurality of shaped bodies which collectively provide a textured, three-dimensional abrasive article, e.g., comprising abrasive particles and a binder, wherein the abrasive particles may be in the form of abrasive agglomerates.

The invention provides a relatively low cost, readily controllable method for improving the surface characteristics of a semiconductor wafer at various stages during fabrication. Because the abrasive article is designed to be relatively long-lasting, a single abrasive article may be used in a number of successive operations.

Other features, advantages, and constructs of the invention will be better understood from the following description of figures and the preferred embodiments of the present invention.

Brief Description of the Drawings

Figures 1 through 20 relate to various fixed abrasive articles. Figures 2, 11, and 13-20 relate to embodiments of fixed abrasive articles and processes that include wear indicators.

Detailed Description

A fixed abrasive article is an abrasive article capable of removing material from a surface of a workpiece, especially in the presence of an appropriate working fluid. Preferred fixed abrasive articles can be of the type that include an abrasive composite. Abrasive composites are known in the art of fixed abrasive articles, and may include polymeric materials, phase separated polymeric materials, or a combination of either or both of these with abrasive particles such as inorganic or polymeric abrasive particles. As an example, an abrasive composite can comprise a binder and optionally inorganic abrasive particles dispersed throughout the binder. As another example, an abrasive composite can comprise a polymeric material having separate phases, with one phase acting as abrasive particles.

The fixed abrasive article can be an integral abrasive article that is substantially free of unattached abrasive particles except as may be generated during use. Preferably, the fixed abrasive article can be "three-dimensional," "textured," "erodable," or a combination of these. A "three-dimensional" fixed abrasive article is a fixed abrasive article having abrasive particles dispersed throughout at least a portion of its thickness such that removing some of the particles during planarization exposes additional abrasive particles. A "textured" fixed abrasive article is a fixed abrasive article having raised portions and recessed portions in which at least the raised portions contain abrasive particles and binder. An "erodable" fixed abrasive article is a fixed abrasive article that breaks down under use conditions in a controlled manner.

The fixed abrasive article of the invention can include an abrasive composite that is a "precisely-shaped" abrasive composite, which is an abrasive composite having a molded shape that is the inverse of a mold cavity used to make the precisely-shaped abrasive composite, and which is retained after the abrasive composite has been removed from the mold. Preferably, the abrasive composite of a precisely-shaped abrasive article is substantially free of abrasive particles protruding beyond the exposed surface of the shape before the abrasive article has been used, as described in U.S. Patent No. 5,152,917 (Pieper, et al.), incorporated herein by reference.

Fixed abrasive articles are known in the abrasive arts, and are described, for example by Rutherford et al. in U.S. Patent No. 5,692,950, Calhoun in U.S. Patent No. 5,820,450, Haas et al. in U.S. Patent No. 5,453,312, Hibbard et al. in U.S. Patent No. 5,454,844, Bruxvoort et al. in U.S. Patent No. 5,958,794, Kaisaki in WO 98/49723, and Ravipati et al. in U.S. Patent No. 5,014,468, the entire disclosures of each of which are incorporated herein by reference.

Binders for fixed abrasive articles are generally known in the art of fixed abrasive articles, and a variety of materials useful as binders are commercially available. The binder can be a polymeric material capable of containing the abrasive particles for use, and can be prepared from one or more reactive chemistries. Preferred binders can be prepared from polymerizable resins, as are known, such as organic polymer resins, e.g. thermoset resins. Examples of preferred resins include acrylate and methacrylate polymer resins. Another type of

suitable binder is a ceramer binder that includes colloidal metal oxide particles in an organic polymer.

Preferably, the abrasive composite can be erodable. Erodibility is desired because it results in abrasive particles being removed from the abrasive article to expose new abrasive particles. Because it can be preferred that the abrasive article be three-dimensional, a plentiful supply of new abrasive particles will be assured. If the abrasive composite is not erodable, the abrasive particles may not properly be discharged from the abrasive article during use, in which case fresh abrasive particles will not be exposed. If the abrasive coating is too erodable, abrasive particles may be expelled too quickly, which may result in an abrasive article with a shorter than desired product life.

For specific applications, the degree of erodibility of an abrasive composite can be a function of a variety of factors, including: the surface textures of the fixed abrasive article and the workpiece, including the shape of the abrasive composite elements; the conditions of use, including the pressure between the fixed abrasive article and the workpiece and whether a liquid is used during the process; and the composition of the substrate.

To facilitate erodibility, the binder preferably contains a plasticizer in an amount sufficient to increase erodibility of the fixed abrasive article relative to the same fixed abrasive article that does not contain plasticizer. Preferably, the binder includes at least about 25% by weight of the plasticizer (more preferably, between about 40% and about 75% by weight) based upon the combined weight of the plasticizer and the resin. Preferred plasticizers are phthalate esters, as well as derivatives thereof. See, e.g., United States Patent No. 5,958,794.

The abrasive particles can be any size, composition, or type that will be useful in the abrasive article, depending on factors such as the particular composition of the abrasive article (e.g., the binder), the workpiece with which the abrasive article is designed to process, and whether or not a liquid is intended to be used during processing. In general, abrasive particles having an average particle size no greater than about 5 micrometers are preferred. Even more preferred are abrasive particles of no greater than about 1 micrometer, in particular no greater than about 0.5 micrometer.

In specific applications, e.g., to avoid harming a surface of a workpiece such as a semiconductor wafer (particularly where the wafer surface is a metal oxide-containing surface such as a silicon dioxide-containing surface), the abrasive particles may be selected to have a Mohs hardness value no greater than about 8. Examples of preferred abrasive particles include particles made of metal oxide materials such as ceria. See also Bruxvoort et al., US. Patent No. 5,958,794, at column 19, lines 6-40, and Kaisaki, WO 98/49723, for other examples of abrasive particles.

The abrasive composite may also contain other particles, e.g., filler particles, in combination with the abrasive particles, in amounts that are understood in the art of fixed abrasive articles. Examples of filler particles include carbonates (e.g., calcium carbonate), silicates (e.g., magnesium silicate, aluminum silicate, calcium silicate, and combinations thereof), and combinations thereof. Plastic filler particles may also be used.

Abrasive composite elements can take any useful form or shape, positive or negative, with preferred shapes including cylindrical, cubical, truncated cylindrical, prismatic, conical, truncated conical, truncated pyramidal, cross, post-like with flat top surface, hemispherical, and combinations of these. Appropriate sizes and spacings of the elements will also be appreciated and understood by a worker skilled in the art of fixed abrasive articles. Generally, useful shapes of the abrasive composite elements can be any shapes that will usefully abrade or polish a selected workpiece, preferably in the form of a three-dimensional, erodable element. Preferably, substantially all of the abrasive composite elements have the same shape.

Abrasive composite elements may be directly adjacent or spaced apart from each other. For example, they may be provided in the form of elongated ridges spaced apart from each other, e.g., such that channels form between adjacent abrasive composite ridge elements. Each of the abrasive composite elements can preferably have substantially the same orientation relative to the backing.

Preferred are fixed abrasive articles that include a plurality of abrasive composite elements arranged in the form of a precisely-shaped pattern. All of the elements preferably have substantially the same height, which is most preferably no greater than about 250 microns.

The fixed abrasive article is preferably long lasting, e.g., able to complete at least two, preferably at least 5, more preferably at least 20, and most preferably at least 30 planarization processes. The abrasive article should preferably provide a good cut rate. Additionally, the abrasive article is preferably capable of yielding a processed workpiece, e.g., semiconductor wafer, having an acceptable flatness, surface finish, and minimal dishing. As will be appreciated by a skilled artisan, the materials, desired texture, and process used to make the fixed abrasive article all influence whether or not these criteria are met.

The fixed abrasive article may preferably contain a backing, as is known. One example of such an article is illustrated in figure 13. In general, abrasive particles are dispersed in a binder to form an abrasive composite bonded to the backing. Referring to figure 13, abrasive article 50 comprises backing 59 having front surface 58. Abrasive composite 57 is bonded on front surface 58. Fixed abrasive article 50 is textured and three-dimensional, and comprises a plurality of erodable abrasive composite elements 54. The upper surface of the fixed abrasive article, i.e., the side of the fixed abrasive article having a face that includes the abrasive composite elements 54, will be referred to generally as the abrasive surface 52. In the figure, abrasive composite elements 54 are pyramids. There are recesses or valleys 53 between adjacent abrasive composite elements. There is also more than one row of pyramidal abrasive composite elements shown in which the second row of abrasive composite elements is offset from the first row. Abrasive composite elements 54 comprise a plurality of abrasive particles 56 dispersed in binder 55. Outermost point 51 of each abrasive composite 54 first contacts a workpiece during processing, and as processing proceeds the abrasive composite elements wear or erode away substantially uniformly toward backing 59.

Fixed abrasive article 50 of figure 13 includes an example of a wear indicator, which is a visible marker at the base of an abrasive composite element 54, and which is illustrated by shaded portion 60. After an amount of abrasive composite element 54 is worn or eroded away, the visible marker becomes visible at the upper (abraded) surface of fixed abrasive article 50.

Optionally, as illustrated in figure 14, the fixed abrasive article does not require a separate backing. Figure 14 shows fixed abrasive article 600 which

comprises a textured, three-dimensional abrasive body having a textured abrasive surface 602 making up a general abrasive surface 606, and being provided by an integral structure composed of a plurality of pyramidal-shaped abrasive composites 604 in which abrasive particles 601 are dispersed in a binder 603. A visible marker is included as a wear indicator, as represented by shaded area 605.

Embodiments of the abrasive article can be circular in shape, e.g., in the form of an abrasive disc; an abrasive roll, typically referred to in the abrasive art as an abrasive tape roll; or in the form of an endless abrasive belt.

Measuring Wear of Fixed Abrasive Articles Using Wear Indicators

The fixed abrasive articles of the invention allow for measurement of the wear or remaining useful lifetime of a fixed abrasive article, e.g., to determine useful, convenient, optimal, or excessive degree of wear of a fixed abrasive article. In preferred methods, this can be accomplished during processing of a workpiece, and without having to interrupt processing to view the stationary fixed abrasive article; i,e., without interrupting processing for the purpose of displacing the fixed abrasive article from contact with the workpiece, and possibly stopping motion of the fixed abrasive article, to allow viewing of the fixed abrasive article and the amount of wear it has experienced. The fixed abrasive articles allow a determination of whether or when a fixed abrasive article should be replaced with a fresh fixed abrasive article. Replacing the fixed abrasive article after an optimal amount of wear eliminates the possibility of damaging substrates by using too much of the fixed abrasive article, and creates efficiency by minimizing the number of times that fixed abrasive articles are replaced, therefore reducing over time the total amount of process down-time required to replace worn fixed abrasive articles.

A wear indicator is a component, feature, shape, or design of a fixed abrasive article that is designed into the article to cause measurable change in the fixed abrasive article during use, and that can be used to measure a change during use in the fixed abrasive article or the process, indicating that the fixed abrasive article has experienced wear, in that the amount of useful abrasive composite that remains a part of the fixed abrasive article has been reduced. In terms of physical makeup or composition, the wear indicator can be a component, feature, shape, or design of a fixed abrasive article whose composition, position, or incorporation into the fixed

abrasive article is different from the usual composition, position, or incorporation of such a component, feature, shape, or design; a wear indicator would not typically be a normal component of a fixed abrasive article such as binder, abrasive particle, etc., but if its position, design, or incorporation in the fixed abrasive article is designed to produce a detectable change upon wear of the fixed abrasive article, such a feature of the fixed abrasive article could be considered a wear indicator.

Preferred wear indicators are added to those other normally necessary materials and features of the fixed abrasive article, such as necessary binder and abrasive materials. Examples of preferred wear indicators involve the use of materials that affect a visual property of a fixed abrasive article or a process using the fixed abrasive article, such as a colorant or dye; a transparent material that is transparent to some form of radiation or that can be measured in terms of an index of refraction; detectable materials such as magnetic or metallic materials; materials that are chemically detectable, either directly or indirectly, e.g., through a chemical reaction or change in pH; or, the wear indicator can be a shape or form of a fixed abrasive article such as a void or an aperture in the fixed abrasive article that becomes visible or otherwise detectable after a certain amount of wear occurs, or that can be used to monitor another process parameter or physical feature of the process that will change with wear of the fixed abrasive article.

The wear indicator can operate according to any chemical, physical, mechanical, electrical or other principle. Examples include the following: the wear indicator may operate using principles of electricity with electrical devices such as capacitors or other capacitive, inductive, resistive, or conductive devices (e.g., if a wear indicator is or has properties of one of these devices or can be detected by any of these devices or related principles); principles of optics, by monitoring changes in color or refractive index of a fixed abrasive article, a wear indicator, or another component or aspect of a process that uses the fixed abrasive article, such as may even incorporate the workpiece or a liquid used in the process; the principles relating to magnetism, e.g., by use of a magnetic wear indicator such as a magnetic wear bar, a magnetic film, magnetic powder, magnetic paint, or any other magnetic material; principles relating to friction between a fixed abrasive article and a workpiece, i.e., as the fixed abrasive article experiences wear and abrasive composite erodes away, the moving force of friction between the fixed abrasive article and the substrate either

increases or decreases resulting in an increase or decrease in motor torque that can be easily measured (e.g., contact between the wear indicator and the fixed abrasive article may increase or decrease the amount of friction between the fixed abrasive article and the substrate); or, the wear indicator may operate by making a noise or even further abrasion, e.g., a scratch, in the workpiece, upon contacting the workpiece (although these alternatives may not be preferred if they may damage the substrate). The choice of an operative principle to be used and the selected components of the fixed abrasive article may depend on a large number of factors such as the choice of the workpiece, the processing equipment, the desired precision of the process, and dimensions of the workpiece or the fixed abrasive article.

Generally, wear indicators that relate to features that can be readily and visually observed, e.g., using visual optics, can be preferred. As an example, a wear indicator may operate on principles of a change in a visual property of a fixed abrasive article that occurs with wear of the fixed abrasive article.

The change may be a gradual change that can be measured and monitored throughout the life and use of the fixed abrasive article, or it may be an abrupt, rapid, or sudden, visual change such as a visual marker that is uncovered after an amount of wear, or that is visible until the marker is abruptly worn away from a surface of the fixed abrasive article.

More generally, exemplary wear indicators include those that cause a feature or property of the fixed abrasive article to change as the fixed abrasive article wears. Whether the change is gradual or abrupt, the wear indicator preferably causes a feature or property of the fixed abrasive article to change in a predictable, detectable and measureable fashion wherein that change can be correlated to a degree of wear of the fixed abrasive article. This type of a wear indicator can operate by becoming detectable or undetectable, or by becoming relatively more or less detectable, as the fixed abrasive article wears, especially as abrasive composite elements of the fixed abrasive article are worn or eroded away whereupon the fixed abrasive article experiences or causes a detectable change based on the presence of the wear indicator. Such a wear indicator can be a properly placed visual marker such as a visible pigment, colorant, dye, or the like, incorporated into the fixed abrasive article in a manner that will cause the visual character of the fixed abrasive article to predictably change with use and wear of the fixed abrasive article, especially when

the fixed abrasive article wears down to allow contact between the wear indicator and the workpiece.

As one specific example, a fixed abrasive article can include a visual wear indicator in the form of a colored layer over abrasive composite elements, e.g., over at least a portion of the abrasive surface, or over the entire abrasive surface. Fixed abrasive article 620 illustrated in figure 15 includes a colored layer 622, e.g., a paint, applied over pyramidal abrasive composite elements. The abrasive composite elements can be of any shape, as long as the amount of wear indicator remaining on the fixed abrasive article will change (e.g., be reduced) with use and wear of the fixed abrasive article, and the change can be measured. Preferred shapes can include at least one non-vertical wear surface, such as pyramids or ridges, as shown in figure 15, that will experience a color change when the abrasive surface is viewed. Other examples include hemispherical elements, conical elements, and even cylindrical elements, especially those that include a shoulder, ledge, ring, or other form of a nonvertical surface, e.g., step or a ramp, that if coated with a colored layer will gradually or abruptly change color during use of the fixed abrasive article.

An example of another type of wear indicator is a visual marker such as a visible pigment, colorant, or dye, etc., that becomes visible after an amount of fixed abrasive article is used and worn away The visual marker may be incorporated into the fixed abrasive article in any manner that will cause the visible wear indicator to become visible with use and wear of the fixed abrasive article.

Specific examples of this type of wear indicator include wear indicators that are present at a position that causes the wear indicator to become visible or otherwise detectable (or relatively more or less visible or detectable) after some of the abrasive composite element is worn or eroded away. Figure 2 illustrates exemplary abrasive article 2 comprising abrasive composite elements 4 in the form of posts. The abrasive composite elements 4 include a binder and abrasive particles (the abrasive particles are not specifically shown) and a visible marker, e.g., a visible dye, at a lower portion 10 of the elements 4. During use, portions 6 of the elements that do not contain visible wear indicator, i.e., the portions above the portions 10 that do contain visible wear indicator, will wear or erode away. Upon such erosion down to the level of the abrasive composite element where the visual wear indicator is first present, represented by lines 8 in figure 2, the wear indicator becomes visible. The abrasive

article can then be replaced with a fresh abrasive article. Visual wear indicator may be present in one, several, or all of the abrasive composite elements of such a fixed abrasive article, e.g., in a pattern such as a circle or line, or within all abrasive composite elements of a fixed abrasive article.

The wear indicator of figure 2 need not be visual, but can be any material that becomes detectable upon contact with the workpiece, after wear of the abrasive composite elements. As another example, lower portion 10 may include a chemical, e.g., dispersed or encapsulated, that will evolve from the fixed abrasive article when lower portion 10 contacts the workpiece during processing. The chemical may be directly detectable in the atmosphere of the process or may be indirectly detectable in the effluent or working fluid of the process, for example by reacting with another material to cause a color change, a pH change, or some other detectable chemical phenomena.

The height of the portions 10 of the abrasive composite elements 4 that contain wear indicator can be selected as desired to cause the wear indicator to be detected at a desired time during the life of the article, after a desired amount of wear. This depends to a great extent on the height of the abrasive composite element itself and on the shape of the abrasive composite element. In a general sense, the wear indicator can preferably be included in only the bottom 25 percent (by height) of the abrasive composite element, e.g., the bottom 5 or 10 percent by height. Also, the portions 10 of the abrasive composite article may or may not, as desired, include abrasive particles. Such considerations will be readily understood by one of skill in the art relating to fixed abrasive articles.

Another example of a wear indicator is depicted at figure 11. In this embodiment a wear indicator element 12 (represented by the shaded area), i.e., a "wear indicator composite," comprising a binder and a wear indicator, is located in an abrasive article 16 in a space between abrasive composite elements 14. The wear indicator element 12 is not necessarily a portion of an abrasive composite element (although it may well include a binder and abrasive or other particles), because it does not have to take on the shape or composition of a fixed abrasive composite element. Here, wear indicator element 12 can be considered a separate component of the fixed abrasive article, shown in this example to be attached to abrasive composite elements 14. The upper surface of wear indicator element 12 comes into contact with a surface

of a substrate when adjacent posts 14 have worn down to the level of the surface of wear indicator element 12. Wear indicator element 12 then provides some indication that the wear indicator element 12 is contacting the substrate. This indication can be, e.g., by a visual indication, for example a color change, e.g., a color may appear or disappear upon abrasion of the surface of the wear indicator element 12; by a magnetic indication, e.g., by sensing a magnetic wear indicator coated on the top surface of wear indicator element that upon contact with the substrate will abrade away; by an increase in friction or abrasion caused by the contact; by the presence of another type of material eroded out of the wear indicator element 12 such as a chemical that is directly or indirectly detectable in the effluent, working fluid, or atmosphere of the process; or by any other effective mechanism. Wear indicators of this type may be placed at one or at numerous different positions throughout an abrasive surface of a fixed abrasive article, e.g., between abrasive composite elements. There may be one or a number of such wear indicators over a surface of a fixed abrasive article, and a group of wear indicators may optionally form a pattern such as a line or circle that will be visible during use, e.g., while the abrasive article is spinning or otherwise moving.

In figure 11, the wear indicator element 12 of abrasive article 16 can be comprised of any of the previously-identified materials useful for wear indicators, including a binder, and including any one or more of a visual marker, a metallic material, a magnetic material, etc., or an abrasive material such as abrasive particles. As one embodiment, an upper surface of wear indicator 12 can be coated with a colored coating (not shown) that wears away when posts 14 wear down to the level of the upper surface; at that level of wear, the colored coating wears away and causes a change in the fixed abrasive article color that indicates that a degree of wear has occurred.

As yet another example, a wear indicator can be embedded in a known position in a fixed abrasive article, and as the fixed abrasive article wears the relative position of the wear indicator can be monitored to monitor how much of an abrasive composite has worn away. Specifically, such a wear indicator can be in the form of a wear bar or strip such as a detectable, e.g., colored, metallic, or magnetic strip located at or below a surface of a fixed abrasive article, or placed between layers (e.g., a layer of abrasive composite, a sub-pad, or a substrate or backing) of a fixed abrasive article.

As the fixed abrasive article wears, the distance between the wear indicator and the surface of the workpiece will change (e.g., decrease). Such a distance can be measured and monitored, and when a certain distance between the wear bar and the workpiece surface is reached, the fixed abrasive article can be replaced. The distance can be measured directly or indirectly, using the wear indicator, by any suitable technique. As a single example, a distance of a magnetic material from a workpiece surface can be measured using a Hall Effect sensor. A signal strength, as sensed by a read head, could grow in magnitude as the distance closes.

An example of this embodiment is shown in figure 16. In the figure, fixed abrasive article 630 comprises an embedded wear bar 632. The wear bar can be any material that is detectable and whose position can be determined through the abrasive article 630. Examples of useful materials for the wear bar can depend on the composition of the fixed abrasive article and the method used for detecting the position of the wear bar. Some useful materials include metallic materials, magnetic materials, and possibly even colored materials if at least a portion of the fixed abrasive article is transparent to visible light. While figure 16 shows a wear bar, the detectable material may take any useful form. In use, the fixed abrasive article contacts a substrate 640 and wears away abrasive composite elements 604, which reduces the distance 636 between the wear bar 632 and the surface 638 of substrate 640. The distance 636 can be measured by measuring the position of the wear bar 632, and this can be used to keep track of the amount of wear and the useful lifetime remaining of fixed abrasive article 630; i.e., when a certain minimum distance is reached, the fixed abrasive article 630 can be replaced with a fresh fixed abrasive article.

Yet another exemplary type of a wear indicator is an abradable wear indicator that is included in a fixed abrasive article at a position such that the wear indicator can be detected when present but that will wear away after a certain amount of wear of the fixed abrasive article, especially wear of the abrasive composite elements.

Examples of abradable wear indicators can be abradable visible markers, magnetic or metallic paint or other materials, or any other detectable and abradable material placed at a surface of the fixed abrasive article or within a fixed abrasive article at a desired depth.

Figure 11 can be used to illustrate an abradable wear indicator on a surface of a fixed abrasive article. As previously mentioned, the upper surface of wear indicator element 12 can be coated with an abradable wear indicator (not shown) such as a detectable colored, metallic, or magnetic material. During the useful lifetime of fixed abrasive article 16, the abradable wear indicator is present and detectable; upon wear of the abrasive composite elements 14 to and past the level of the surface of the wear indicator element 12, the abradable wear indicator coated at the surface of the wear indicator element 12 will abrade away and no longer be detectable.

Figure 18 illustrates an abradable wear indicator located below a surface of, e.g., embedded in, a fixed abrasive article 618. Abradable wear indicators 607 are located below abrasive surface 602, embedded in abrasive composite elements 604 at a depth that will cause them to be detectable while present, but where they will be worn or abraded away as abrasive composite elements 604 wear down. The depth of abradable wear indicators 607 can be a depth below surface 602 that will cause the indicators 607 to wear away at a desired, optimal, or convenient time during the life of fixed abrasive article 600. Also, while figure 18 shows three abradable wear indicators in the form of linear elements or bars, any number and any size or shape, may be used.

As described, wear may be measured in some embodiments of the invention by monitoring a change observable in a characteristic of the abrasive surface of the fixed abrasive article, by observing the abrasive surface (i.e., "front-side") of the fixed abrasive article. Other embodiments of wear indicators can be used by observing the backside of the fixed abrasive article, especially through a window, hole, or other aperture in the fixed abrasive article and its mounting.

Some examples of wear indicators that might be monitored from the back-side of the fixed abrasive article include wear indicators that are viewable through the abrasive article, either because the abrasive article is transparent to a mechanism used to sense the wear indicator (e.g., "sensing radiation"), or because an aperture is included in the fixed abrasive article. The mounting must also be designed to allow monitoring of the wear indicator from the backside.

One example of a wear indicator that can be observed from a backside of a fixed abrasive article is a wear indicator that works on the principle of optics, wherein wear of the fixed abrasive article causes one or more of: a change in the optical nature

of a path through the fixed abrasive article, or a change in the optical nature of a path through the fixed abrasive article and to the workpiece, possibly through a liquid used with the fixed abrasive article in modifying the workpiece.

More specifically, a fixed abrasive article as illustrated in figure 17 can include a transparent wear indicator 646 in the form of a solid but transparent window, e.g., aperture (hole), glass, polycarbonate, or another material that is transparent to a type of sensing radiation, and that allows a sensing radiation, e.g., in the form of a beam, to pass through the window and back. The transparent wear indicator does not have to be transparent to visible radiation, and radiation other than visible radiation can be useful.

The optical properties of the wear indicator can be monitored to determine when the wear indicator contacts the workpiece. This can be accomplished, for example, by measuring an optical property of the path 648 starting below the fixed abrasive article 644 and moving upward through the wear indicator 646, through space 642, and to surface 638 of workpiece 640. The optical property may be a color or an index or refraction, or the like. During use of fixed abrasive article 644, abrasive composite elements 604 maintain a distance and a space 642 between wear indicator 646 and surface 638 of workpiece 640. Space 642 can be detected from the backside, i.e., underside, of fixed abrasive article 644 by monitoring an optical property of the wear indicator and the space. Space 642 between wear indicator 646 and workpiece surface 638 will exhibit optical properties such as color and index of refraction that can be detected through wear indicator 646. The optical property will be affected by the optical properties of the workpiece and optical properties of any liquid used in processing. The liquid may be present in space 642, as may air, and the presence of either or both will affect optical properties along line 648. When abrasive composite elements 604 wear away to a degree that wear indicator 642 contacts substrate surface 638, the optical property being measured will change in a predictable fashion because space 642 will be eliminated and the optical properties observed through the wear indicator along line 648 will be essentially the properties of wear indicator 646 in contact with workpiece surface 638 (perhaps through a thin layer of air or liquid). Observation of these optical properties can be correlated to the amount of wear and the remaining life of the fixed abrasive article.

Figure 19 illustrates how a wear indicator can take the shape, form, or design of a fixed abrasive article, e.g., a form, shape, design of an abrasive composite or a wear indicator composite, and in the figure, the form of a void or apperature designed into the fixed abrasive article. Specifically, fixed abrasive article 619 includes voids 608 extending partially through fixed abrasive article 619, starting from the bottom. Upon wearing of the portions of abrasive composite elements 604 located just above voids 608, the voids will become visible apertures through the fixed abrasive article. These can be detected visually or based on a change in the frictional forces between the fixed abrasive article and a substrate, or otherwise.

As an alternative embodiment, not illustrated, a wear indicator may take the form of an aperture through the fixed abrasive article, that is used to introduce a working fluid to the process. The aperture may be through any portion of the fixed abrasive article, such as through an abrasive composite element in the form of a post, or at an area between abrasive composite elements, e.g., defining a pore or groove. This type of wear indicator can be used by monitoring a process parameter that relates to the aperture, that changes during wear of the fixed abrasive article. For example the pressure or leakage rate of the working fluid flowing through the aperture will change with the gradual wearing away of the fixed abrasive article, and can be correlated (during processing) to the degree of wear of the fixed abrasive article.

As yet another possibility, a wear indicator can be of a type that can be monitored through the workpiece, e.g., either a workpiece that is transparent to some type of sensing radiation, or that includes holes or apertures that allow viewing of the fixed abrasive article, the workpiece, a liquid involved in processing, or a combination of these. An example of a transparent workpiece is a glass workpiece such as a television faceplate polished using diamond polishing techniques. Visual wear indicators that change color gradually or abruptly, either by appearing, fading, or disappearing, can be particularly useful with a transparent substrate, but other types of wear indicators will also be useful.

Other embodiments of wear indicators incorporated into fixed abrasive articles will be apparent from the foregoing disclosure, and might include one or more of the above concepts and specific product embodiments, or others. For example, a wear indicator may be in the form of a marker at the base of an abrasive

composite element of any of the various useful shapes and sizes of abrasive composite elements, or as a component located between abrasive composite elements of any shape.

The fixed abrasive articles can be used in modifying the surface of a workpiece (also sometimes referred to as a "substrate"). Some methods of using the fixed abrasive articles are apparent from the description above, but also relate to the more specific examples as follows.

The workpiece may be any workpiece that can be processed, e.g., abraded, polished, or otherwise modified, using a fixed abrasive article. Preferred processes involve the modification of a surface of a semiconductor, especially but not necessarily by incorporating methods of chemical mechanical polishing.

A semiconductor substrate can comprise a microelectronic device such as a semiconductor wafer. A semiconductor wafer may comprise either a substantially pure surface or a surface processed with a coating or another material. Specifically, a semiconductor wafer may be in the form of a blank wafer (i.e., a wafer prior to processing for the purpose of adding topographical features such as metallized and insulating areas) or a processed wafer (i.e., a wafer after it has been subjected to one or more processing steps to add topographical features to the wafer surface). The term "processed wafer" includes, but it is not limited to, "blanket" wafers in which the entire exposed surface of the wafer is made of the same material (e.g., silicon dioxide). One area in which the method can be useful is where the exposed surface of a semiconductor wafer includes one or more metal oxide-containing areas, e.g., silicon dioxide-containing areas.

It is generally desired to modify a workpiece surface to achieve a surface that is more "planar" and/or more "uniform" and/or less "rough" than the workpiece surface prior to treatment. The particular degree of "planarity," "roughness," and/or "uniformity" desired will vary depending on the individual workpiece and the application for which the workpiece is intended, as well as the nature of any subsequent processing steps to which the workpiece may be subjected. In general, however, there are several known methods of measuring "planarity," "roughness," and/or "uniformity."

Methods of modifying a workpiece surface using a fixed abrasive article are well known, and generally include contacting a workpiece and a fixed abrasive

article with a desired pressure and relative motion, e.g., rotational, linear, or otherwise, between them.

Certain methods, e.g., planarization processes, can be conducted using a liquid in contact with the workpiece and the fixed abrasive article, with the liquid being chosen based on the composition of the workpiece, to provide the desired planarization without adversely affecting or damaging the workpiece.

The liquid may contribute to processing, in combination with the fixed abrasive article, through a chemical mechanical polishing process. As an example, the chemical polishing of SiO_2 occurs when a basic compound in the liquid reacts with the SiO_2 to form a surface layer of silicon hydroxides. The mechanical process occurs when an abrasive article removes the metal hydroxide from the surface.

The pH of the liquid may affect performance of the abrasive article in modifying a workpiece, and can be selected as desired, based on the nature of the workpiece surface being planarized, including the chemical composition and topography. Where the workpiece comprises a silicon wafer surface that also contains a metal oxide (e.g., silicon dioxide), the liquid may be an aqueous medium having a pH greater than 5, preferably greater than 6, more preferably greater than 10. A pH in the range from 10.5 and 14.0 can be preferred, e.g., from about 10.5 to 12.5. Examples of suitable chemistries for use with a copper workpiece are described in Kaisaki WO 98/49723, and in Assignee's copending United States Patent Application Serial Number 09/266,208, filed March 10, 1999, and incorporated herein by reference.

Examples of liquid media suitable for use in modifying metal oxide-containing wafer surfaces include aqueous solutions containing hydroxide compounds such as potassium hydroxide, sodium hydroxide, ammonium hydroxide, lithium hydroxide, magnesium hydroxide, calcium hydroxide, barium hydroxide, and basic compositions containing compounds such as amines and the like. A basic liquid medium may also contain more than one basic material, e.g., a mixture of potassium hydroxide and lithium hydroxide. An example of a metal hydroxide-containing liquid medium is a solution of potassium hydroxide in deionized or distilled water in which the potassium hydroxide concentration ranges from about 0.1 to 0.5% (e.g., about 0.25%).

The liquid may also include a chemical etchant, especially in modifying a surface of a semiconductor wafer. Although not wishing to be bound by theory, it is theorized that a chemical etchant may "attack" and possibly react with an outermost surface of a semiconductor wafer. The abrasive article then removes the resulting material formed on the outermost surface of the semiconductor wafer. Examples of chemical etchants include strong acids (e.g., sulfuric acid, hydrofluoric acid, and the like) and oxidizing agents (e.g., peroxides).

The liquid may also, if desired, help break down the surface of a fixed abrasive article, thereby increasing the erodibility and the rate of erosion of the fixed abrasive article during use. For example, where the fixed abrasive article includes an abrasive composite containing a water-soluble binder or a water-sensitive filler such as wood pulp, a water-containing liquid medium will result in water dissolving or being absorbed into the abrasive coating, thereby enhancing erodibility of the fixed abrasive article.

The liquid may also contain additives such as surfactants, wetting agents, buffers, rust inhibitors, lubricants, soaps, and the like. These additives are chosen to provide desired benefits while avoiding damaging a workpiece surface. A lubricant, for example, may be included to reduce friction between the fixed abrasive article and a semiconductor wafer surface during planarization.

Inorganic particulates may also be included in the liquid. These inorganic particulates may aid in the cut rate. Examples of such inorganic particulates include: silica, zirconia, calcium carbonate, chromia, ceria, cerium salts (e.g., cerium nitrate), garnet, silicates and titanium dioxide. The average particle size of these inorganic particulates should be less than about 1,000 Angstroms, preferably less than about 500 Angstroms and more preferably less than about 250 Angstroms.

The amount of the liquid is preferably sufficient to be useful with a particular substrate, e.g., to aid in removal of metal hydroxide deposits from a surface of a semiconductor wafer.

After processing of a workpiece is complete, the workpiece can be processed as desired, e.g., a semiconductor wafer is typically cleaned using procedures known in the art.

During use in modifying a surface of a workpiece, the fixed abrasive article can preferably be secured to a sub-pad. The sub-pad allows for processing of the workpiece, including contacting the fixed abrasive article to the workpiece, wherein the contact pressure between the workpiece surface and the fixed abrasive article (i.e., the total wafer backside pressure) depends at least in part on the particular abrasive article. In general, the contact pressure preferably does not exceed about 10 psi.

According to the invention, processes using the fixed abrasive article to modify a surface of a workpiece can make use of the wear indicator to monitor the use, remaining life of, or the need to replace the fixed abrasive article. The fixed abrasive article, can be monitored in any fashion to detect a change indicating that a threshold amount of wear has occurred on the fixed abrasive article. Examples of changes include changes in the form or a property of the wear indicator, such as its visibility or detectability by other visual, optical, or non-visual properties. Specifically, the wear indicator may become detectable, e.g., visible, especially after abrasive composite elements are worn down to an extent that the wear indicator contacts the substrate, or nearly so; simple contact between the wear indicator and the workpiece, as measured by a noise, added friction, scratching or abrasion of the surface of the workpiece, or a visual indication; a change in form or a property of the fixed abrasive article, e.g., its color or average color; a change in the distance or spacing between the workpiece and the wear indicator, for the substrate being less than a minimum distance from the wear indicator, as measuring the position of the wear indicator; etc.

As a specific example, a wear indicator can be a visual marker such as a dye, and the process using the fixed abrasive article can include visually monitoring the abrasive surface of the fixed abrasive article. This can be done either by displacing the abrasive article from contact with the workpiece, or, preferably, by setting up a mechanism for visually monitoring the abrasive article during use and while the article remains in contact with and continues to process the workpiece. Preferably, continuous monitoring of the abrasive article during use can be accomplished, for example, using a fixed abrasive article in the form of a belt, wherein the belt moves around rollers and a surface of the belt contacts the workpiece, optionally with motion of the workpiece. Such processing methods are well known and understood in the art

of processing using fixed abrasive articles. Because the entire surface of the abrasive article belt does not contact the workpiece during use, the belt can be monitored visually and when a visual wear indicator becomes visible, the belt can be changed. Visual monitoring can be done by a worker or may be done electronically.

Figure 20 illustrates a simplified apparatus for planarizing semiconductor wafers using fixed abrasive articles of the invention. Apparatuses of the type illustrated and numerous variations and other types of apparatus are well known for use with polishing pads and loose abrasive slurries. An example of a suitable commercially available apparatus is a CMP machine available from IPEC/WESTECH of Phoenix, AZ.

As shown in Figure 20, apparatus 30 comprises head unit 31 that is connected to a motor (not shown). Chuck 32 extends from head unit 31; an example of such a chuck is a gimbal chuck. Chuck 32 preferably is designed to accommodate different forces and pivot so that the fixed abrasive article can maintain desired surface finish and flatness on the wafer.

At the end of chuck 31 is wafer holder 33 to help secure semiconductor wafer 34 to head unit 31 and prevent the semiconductor wafer from becoming dislodged during planarization.

The speed at which wafer holder 33 rotates will depend on the particular apparatus, planarization conditions, abrasive article, and the desired planarization criteria. In general, however, wafer holder 33 rotates between about 2 to about 1,000 rpm, typically between about 5 to about 500 rpm, preferably between about 10 to about 300 rpm and more preferably between about 30 to about 150 rpm. If the wafer holder rotates too slowly or too fast, then the desired cut rate may not be achieved.

Wafer holder 33 may rotate in a circular fashion. Optionally, as wafer holder 33 rotates, the wafer holder may oscillate or vibrate e.g., in a circular spiral, figure eight, corkscrew, or other uniform, nonuniform, or random fashion. Preferably, the size of fixed abrasive article 39 is larger than the size of wafer holder 33, and furthermore, the process includes motion between the fixed abrasive article 39 and the wafer holder 33 such that the wafer holder 33 moves relative to the fixed abrasive article 39 and contacts different areas of the fixed abrasive article surface 42. The relative sizes of fixed abrasive article 39 and wafer holder

33 can be sufficient that a portion of the surface area of the fixed abrasive article does not contact the workpiece, and therefore remains visible. The visible area can be monitored.

The fixed abrasive article will typically have a diameter between about 10 to 200 cm, preferably between about 20 to 150 cm, more preferably between about 25 to 100 cm. The abrasive article may rotate between about 5 to 10,000 rpm, typically between about 10 to 1000 rpm and preferably between about 10 to 250 rpm. It is preferred that both the semiconductor wafer and the fixed abrasive article rotate in the same direction. However, the semiconductor wafer and the fixed abrasive article may also rotate in opposite directions.

Apparatus 30 also has base unit 41 which holds fixed abrasive article 39 having abrasive surface 42. Sub-pad 40 is connected to base unit 41 and is attached to fixed abrasive article 39. In general, the sub-pad should be resilient such that during planarization the fixed abrasive article will planarize the entire semiconductor wafer surface. It is preferred that sub-pad be made from a conformable material such as a polyurethane foam.

A preferred embodiment of the process can be as follows. A three-dimensional, textured fixed abrasive article is provided that comprises a plurality of abrasive composite elements bonded to a backing, the abrasive composite elements comprising a plurality of abrasive particles and a binder. A wear indicator is included in any of the various forms such as a visual marker, e.g., a dye present at a base of one or more abrasive composite elements, and in an amount and position that will become visible after a pre-determined amount of the abrasive composite elements are worn or eroded away during use.

A sub-pad is attached to and generally coextensive with the backing of the fixed abrasive article. The sub-pad comprises: at least one resilient element having a Young's Modulus of less than about 100 MPa and a remaining stress in compression of at least about 60%; and at least one rigid element generally coextensive with and interposed between the resilient element and the backing of the fixed abrasive article, wherein the rigid element has a Young's Modulus that is greater than that of the resilient element and is at least about 100 MPa. Suitable sub-pad constructions are disclosed in U.S. Patent Number 5,962,950.

The abrasive article can be in the form of a disc having a diameter that is appropriate for the workpiece, e.g., typically greater than 25 cm, often greater than 36 cm and sometimes greater than 50 cm in diameter.

Referring to figure 20, reservoir 37 holds liquid 43 which is pumped through tubing 38 into the interface between semiconductor wafer 34 and abrasive surface 42.

During planarization there can optionally be a consistent flow of the medium to the interface between the abrasive article and the semiconductor wafer.

Figure 20 also illustrates how wear of a fixed abrasive article can be monitored according to the invention, using a visual wear indicator. Figure 20 illustrates a photodetector 49 that monitors the color of fixed abrasive article 39. During processing, abrasive composite elements of fixed abrasive article 39 wear down or erode, exposing a visual (e.g., colored) marker that can be detected by photodetector 49. When the visual marker is detected, fixed abrasive article 39 is understood to be worn and can be replaced with a fresh fixed abrasive article.

Production of Fixed Abrasive Article Comprising a Wear Indicator

Fixed abrasive articles of the invention can be prepared by known techniques of preparing fixed abrasive articles, and one of ordinary skill in the arts of abrasives and fixed abrasive articles will understand how a wear indicator can be incorporated into a fixed abrasive article.

A generally-stated method of providing a three-dimensional, textured, fixed abrasive article is as follows. A slurry containing a mixture of a binder precursor and abrasive particles is applied to a production tool having cavities which are the negative of the desired shape of a textured surface of a fixed abrasive article. A backing is brought into contact with the exposed surface of the production tool such that the slurry wets the surface of the backing. Then the binder can be at least partially solidified, cured, or gelled. The fixed abrasive article can be removed from the production tool and fully cured if it was not fully cured in the previous step. Alternatively, the slurry can be applied to the surface of the backing and then the production tool can be brought into contact with the slurry on the backing. The abrasive composite thereby takes the form of a plurality of abrasive composite elements adhered to the backing.

A wear indicator can be incorporated into the fixed abrasive article using techniques that will be apparent to those skilled in the art of manufacturing fixed abrasive articles. These can include incorporating the wear indicator into an uncured binder precursor used in preparing the fixed abrasive article, e.g., incorporating the wear indicator into some or all abrasive composite elements of a fixed abrasive article, as desired, preferably at a consistent depth.

A wear indicator taking the form of a detectable material coated over a portion or the entirety of an abrasive surface of a fixed abrasive article can be prepared by simply applying such a coating to at least a portion of the fixed abrasive article.

Other methods can be used to produce a fixed abrasive article wherein a wear indictor is incorporated into, e.g., embedded into, abrasive composite elements or wear indicator composite elements, or even a backing or any other component of the fixed abrasive article.

Generally, a wear indicator can be provided in a backing or between a backing and abrasive composite elements of a fixed abrasive article, or any other layer, by lamination or coating techniques.

As another example, cavities of a production tool may be partially filled with a slurry that contains binder precursor and abrasive particles, and the slurry may optionally be partially or fully cured. A wear indicator may be applied to the open surface of the slurry. For example, a layer of a visual indicator, e.g., a paint or a dye, may be coated over the open surface, and the remaining cavity space can be filled. Alternatively, after partially filling the cavities, a precursor (a "wear indicator precursor") comprising a binder precursor and a wear indicator such as a dye or pigment, could be used to partially or fully fill the remaining space of one or more of the tool cavities. The wear indicator precursor contains a binder precursor or another curable or hardenable material, which may then be fully or partially cured, and the cavities, if not already full, may be filled to completion. For convenience, efficiency, or cost, wear indicator precursor need not include abrasive particles. More generally, the space or spaces of the cavities filled after the wear indicator precursor has been added need not contain abrasive particles, because the wear indicating portion of the abrasive article need not function as an abrasive, although it of course may, if abrasive particles are included therein.

Another method of providing a three-dimensional, textured, fixed abrasive article with a wear indicator is generally as follows. A backing having a contour generally corresponding to the desired shape of the textured surface is provided. A slurry of abrasive particles in a binder precursor is then coated onto the contoured surface of the backing and cured in such a manner that the cured abrasive composite will have a textured surface corresponding generally to the contour of the backing. A wear indicator may be incorporated into the fixed abrasive article produced by this method, e.g., by locating a marker at or below a surface of the backing, at a depth and position that will cause the marker to become detectable after an amount of wear occurs on the abrasive composite elements. Alternatively, the marker can be incorporated into the slurry in positions that will cause the marker to detectably change or to become detectable after an amount of wear occurs on the abrasive composite elements. A visual marker disposed throughout the slurry will produce a product analogous to that of figure 15 that will change in color as the abrasive composite element formed from the slurry wears away and exposes the backing (of a different color).

Certain additional modifications may be made in the a fixed abrasive article to improve or otherwise alter performance. For example, the abrasive article may be perforated to provide openings through the abrasive layer and/or the backing to permit the passage of fluids before, during or after use.

Examples

The inventions disclosed and claimed herein address and solve problems found in the abrasives product and processing arts, improve efficiency, and reducing costs of CMP processing, while maintaining wafer-to-wafer uniformity and the quality of semiconductor devices. The inventions set forth herein are illustrated by the embodiments set forth hereinafter, which are not to be construed as limiting the invention.

Embodiment No. 1

The inventive concept resides in providing a permeable web to introduce chemicals, e.g., a microporous web. Advantages further include preventing air bubbles under the web. The web material itself is permeable to the supply chemicals

A problem which arises during CMP is effective supplying chemicals underneath the wafer resulting in starvation at the wafer center. This would apply to both fixed abrasive and conventional slurry CMP. As the wafer rotates, a leading edge-trailing edge situation arises. But in any case, around the edge of the wafer at some point all of the different points on the edge get to be leading at some point and all of them get to be trailing at some point, but the center is always the center. Adverting to Fig. 1, the leading and trailing edges and chemical concentrations are shown. There may be some depletion across the wafer during rotation and the wafer is rotating around the center of the wafer. Thus, the center of the wafer always experiences some medium chemical concentration. Accordingly, the chemical concentration is going up and down and up and down causing a very unstable situation. This problem is solved by providing a permeable abrasive pad so that the wafer sees a uniform concentration of chemicals everywhere. The web is permeable in a vertical direction, coming up from the bottom. The chemicals would be supplied through the platen itself up directly through the membrane.

Another advantage is that if air bubbles are trapped, by providing a non-flat surface to the abrasive, it would permeate out. The bottom is shown in Fig. 1.

This arrangement is not incompatible with vacuum hold down, because by sucking it through a semipermeable membrane a pressure drop across the membrane occurs and this is what provides the necessary hold down.

Aspects include patterns of vacuum channels on one part and chemical supply channels on another part. The vacuum hold down is, therefore, dispersed evenly enough to get a good hold down on a film without localized tearing. The chemistry supply would go up through the film with proper spacing of the air and chemical supply channels.

Embodiment No. 2

This invention entails impregnating the plastic matrix of a web with process chemicals. Fig. 2, depicts a post of abrasive material. Such posts are typically about 50 microns tall and about 200 microns in diameter. But the shape of it in no way limits the invention. During polishing, the first wafer is at the top of the post, which wears down so that later wafers are exposed to a lower part of the post.

There are a number of different functions performed by the CMP chemistry, e.g., oxidizers, inhibitors, such as corrosion inhibitors, buffers, and chelating agents. Ergo, there are a number of different roles performed that vary somewhat, depending on the particular system, e.g., copper, tungsten or oxide. However, the concept of chemical impregnation would be the same.

For illustrative purposes, in a Cu system, the oxidizers attack the copper and oxidize it to get copper oxide. That performs two functions. Initially, a corrosion barrier is provided where there is no abrasion -- it is self limiting where rubbing does not occur. Therefore, etching stops. But in the high spots, the oxide is more prone to polish than the copper metal. Therefore, the oxide is polished and then reoxidized, polished, and then reoxided. The oxide is not a good enough barrier in the low spots, and that is why some corrosion inhibitors, e.g., BTA, are included to basically assist the oxidizer in capping the surface in the low spots where not undergoing polishing. The mechanical action of polishing on the high spots removes both the oxide layer and the inhibitor so that it initiates a fresh attack of the copper. Chemical buffers are employed to maintain the pH in the solution because these chemicals are pH active -- it is an electrochemical type of a process which is dependent on pH. Chelating agents take the copper in the solution and maintain it in solution so that the material rubbed off is removed instead of redepositing on the wafer.

It is particularly advantageous to impregnate a buffer into the plastic matrix to maintain a desired pH. The buffer impregnated in the plastic matrix is continually supplied at the exact point needed -- right at the point of polishing. Thus, any of the types of chemicals could be supplied into the posts, e.g., buffers, oxidizers, inhibitors, etc.

There are several advantages of putting the chemicals into the posts. One is that it provides a timed release. As the post wears down, more and more chemical is provided in a very controlled manner.

The pad refers to the squishy stuff supplied as a backing either integral or nonintegral with the web material itself, which is the backing film that carries the posts and posts themselves. From a very minimalistic standpoint, the web is the posts and the backing. For the web, as in going reel to reel, it is just the backing and the posts, and the squishy sub-pads are supplied independently. It is the posts themselves that are in contact with the wafer. Thus, as the posts wear down fresh chemicals are

continually exposed for timed release, thereby obtaining a more constant concentration over time right at the point of contact where it is desired.

Moreover, web manufacturers can determine how much chemicals to include, which is more controllable than depending on a technician to refurbish chemicals, since it is always going to be the same concentration depending on your manufacturability position, rather than what is going on in the field or if the equipment is breaking down.

Another aspect comprises introducing a chemical marker down near the bottom of the posts that is inert to the process but detectable, thereby providing a signal when approaching the end of the posts. Such chemicals can include an organic dye, that would not adversely interact with the process chemistry. When it starts getting released it would be very obvious to the eye because of a color change. In addition, optical detectors can be installed in the effluent stream. Another aspect of this embodiment comprises detecting a drift in process uniformity from first wafer to a subsequent wafer, and correcting the drift by suitable chemistry in the posts.

Embodiment No. 3

This embodiment involves forming a fixed abrasive web with a plurality of posts having different shapes, different sizes, different heights, different materials and having different distributions of particles. This provides the ability to tailor a web for different functions, for example, simultaneous CMP of metal and oxide.

This embodiment solves the problem of process drift over time by tailoring a number of posts in contact over time so that when some of them wear down, the wafer starts engaging more and more posts. Another problem stems from a rate difference between initial contact of the posts and subsequent post contact after some CMP. The first contact with lower posts would experience a different rate.

Fig. 3, shows examples of two different shapes. By combining the different shapes on the web the benefits of the different shapes are achieved. Later on in the process, copper, for example, begins to clear over oxide and a barrier layer of Tantalum (Ta) is exposed. The Ta must also be removed stopping on the oxide. This aspect involves tailoring the selectivity, whereas, conventionally, the web is very selective to both Ta and oxide, e.g., about 500 to 1 on Ta and about 250 to 1 on oxide.

Aspects of this embodiment include a web with a selectivity of 1 to 1 to 1, as by strategically formulating the posts with suitable chemistry for targeted etching.

Varying the shape, height and diameter of the posts to obtain different structures or patterns can be easily implemented. Smaller posts have a better removal rate and faster abrasion, because the smaller ones have the ability to dig better.

Embodiment No. 4

This invention includes the concept of varying the compressibility of the web to obtain non-linear compressibility to effectively treat both high and low spots on a wafer. Under compression, the modulus of compressibility would increase significantly as the material is compressed to about 50%, as with common sealant elastomers that are loaded with a silica filler to provide strength and body. As the squishy sealant is compressed, the polymer compresses, but upon filler to filler contact, compression ceases completely, i.e., a very non-linear compressibility. In this embodiment, a post is provided so that when a force is applied, it can compress a certain amount, but then further force doesn't compress it any further, i.e., a non-linear spring. As illustrated in Fig. 4, with a wafer having a high part and a low part, the high part contacts the post and compress it to obtain a large force. Where they are in contact with the low parts, a weak force is obtained. By providing a non-linear force, part of the wafer protrudes a number of microns beyond a low spot and compresses a post to a greater extent making it even stiffer so that it pushes back harder. The modulus of compressibility of the post can be changed by suitable crosslinking in the polymer, varying the amount of filler, or changing the nature of the polymer, e.g., a more linear polymer or a more trifunctional or even a quadrifunctional polymer. This is well known art in the polymer industry.

The inventive concept is that, as the wafer is pressed down, in the limit, only the high points on the wafer will automatically contact the pad for polishing. Each post will vary in its modulus of compressibility depending on the amount of force applied to it. Thus, each post is similar to a little spring and the frictional force varies with the applied force. In a linear spring, the force is relatively constant with displacement. However, with non-linear springs, as in this embodiment, if sufficient pressure is applied, the force dramatically increases, thereby automatically applying greater force to the high spots on a wafer vis-a-vis low spots.

Embodiment No. 5

Advantageously, a fixed abrasive polishing web comprising a heat dissipating material can overcome the problems associated with excess heat build-up during polishing. In an aspect of this embodiment, the heat dissipating substance is incorporated into the posts and/or associated backing sheet. Thermally conductive materials include a metal powder, e.g., iron, nickel, copper, zinc, tin, lead, silver, gold, titanium, tungsten, palladium, bismuth, indium, gallium, aluminum and alloys thereof, metallized polymers or metallized ceramics such as alumina, silica, glass, polyamide, polystyrene, polyetheramide, polyacetylene, polyphenylene, polyphenylene sulfide, polypyrol, polythiophene, and graphite. The conductive elements may be provided in many forms, such as for example, particles, wires, filaments, and metallized flakes. The elements may have a wide variety of regular and irregular shapes, as for example, spheres, rods, flakes, and filaments. The binder can be a thermoplastic or a thermosetting-type polymer or a monomer which will polymerize to form the thermally conducted substrate having the thermally conducted elements therein.

Embodiment No. 6

This embodiment relates to a fixed abrasive web comprising a plurality of elongated posts on a sheet. Conventional posts have a diameter of about 125 to 1,000 microns, with the diameter about twice the height. Accordingly, conventional posts extend up to 500 microns above the backing sheet. The present embodiment comprises forming posts with a ratio of the height to diameter opposite conventional practices, so that the posts are significantly higher than their diameter. In this way, a multiplicity of very tall posts are formed, as shown in Fig. 5. Instead of polishing on their upper edges, these tall posts lean over like bristles and polish on their sides that wear off during CMP. Thus, the tall posts are formed so that they lean over during CMP and flow brushing from the side and round off at the top.

Advantageously, according to this embodiment, only a small amount of force is required to bend over the individual posts. However, the force would increase as the taller posts bend to contact each other any are stacked upon each other side by side. At this point, the down force gets compressed. Aspects of this embodiment

include forming posts having a height of about one micron to about ten microns and spaced apart about one micron to about ten microns.

Embodiment No. 7

This embodiment comprises preconditioning fixed abrasive articles comprising a plurality of posts so that the posts have equal heights above the backing to achieve a uniform texture, i.e., uniform abrasive surface on the posts. In this way, each post has exactly the same top surface, i.e. uniform surfaces and uniform heights. This objective can be implemented by physical dressing, as by an abrasive material which is harder than the abrasive material of the posts, pre-seeding with a slurry including polishing debris. By pre-seeding employing polishing debris, the first wafer effect is eliminated. The first wafer effect is conventionally encountered and involves initial non-uniformity with the initial wafer. It is believed that subsequent wafers are polished in the presence of polishing debris. Accordingly, by pre-seeding with polishing debris, the first wafer effect is eliminated.

Another aspect of the present invention comprises the use of a laser to precondition the posts. See Fig. 6.

Embodiment No. 8

This invention relates to improvements with respect to in situ rate measurement (ISRM) devices. The ISRM device is a laser base device that shines a light though the web material to provide a measurement of film thickness. The web material is a composite of abrasive filler and a polymer binder. The dispersed particles typically have a different refractive index than the matrix thereby resulting in scattering. It is therefore, very difficult to get the laser through with detectable intensity, particularly since it has to make the trip twice, (i.e.) it has to go in reflect and come back out. This embodiment solves that problem changing the refractory index of the polymer matrix to match that of the abrasive particles. The refractory of the polymers can easily be adjusted to match it to about that of the refractory index to obtain totally clear material. See Fig. 7.

Embodiments of the present invention include abrasive particles and binders made of a laser light transparent material. For example, both abrasive particles and the binder can be made of a transparent polymer, e.g., a polyurethane, a

polycarbonate, an epoxy resin; inorganic minerals, e.g., sapphire, glass, quartz; or hard organic or semi-organic materials, e.g., diamond or germanium.

Embodiment No. 9

The invention resides in forming a fixed abrasive web with negative posts, as in U.S. Patent 5,014,468 and incorporating chemicals in the negative recesses. Typically, the posts form about 10-25 percent of the surface of the pad, leaving at least about 75% as open channel, i.e., a connected phase employing terminology from percolation theory. The connected phase is the one connected all the way through. The open space is the connected phase; the posts are disconnected from one another. This embodiment reverses the conventional fixed abrasive pad by making the open space the disconnected phase and making the posts the connected phase, thereby maintaining the same relative amount of post area. However, a region can be walled off or damned, as by forming a hexagonal recess which is isolated, such that the posts constitute walls around these isolated recesses. In the process of contacting the web and the wafer, the chemicals are supplied in these recesses. The chemicals are primarily liquid and the concern with the posts where the open spaces, the connected phases, is that the liquid can mix around and go around. If the chemicals are supplied in these isolated recesses, then the chemicals are going to be transported with the web and remain in one place. Therefore, the chemistry is basically isolated through a number of different little cells, each cell a pocket. A circuitous or tortuous path can be formed between the posts so that you're not totally isolated, but effectively isolated. See Fig. 8.

Embodiment No. 10

This embodiment resides in proving a non-homogenous web with different areas to perform different functions, thereby providing greater flexibility. For example, posts can be used to perform buffing. This embodiment provides macroscopic regions of the web which are different for different functions. For example, one area of the web can be for copper polish and another area for example, would remove Ta, thereby achieving a macroscopic effect. This can be easily implemented in round/round polishing when the wafer travels around in a circle on the web material, and it rotates in its place. See Fig. 9.

The wafer effectively describes a circle around on the web material and, therefore, the track of the center is at a uniform distance in a circular path around on the web. However, the edges sometimes extend further out and sometimes further in, because they are also rotating as the wafer goes around. Accordingly, polishing is enhanced, as, for example, at the center, versus the edge, by introducing a strip of material where the center would spend more time over that strip. The concept includes altering the behavioral performance of the web in different regions, in macroscopic regions, to alter performance of for example, under the edge on the wafer.

Embodiment No. 11

The problem addressed by the present invention is that the conventional web backing material, i.e., believed to be a polyester-based material, sheds on abrasion. Frictional interaction between the platen and the web during advancement generates particles in the process. The solution to this problem resides providing a non-shedding backing material, such as a self-lubricating plastic. Such self-lubricating plastics are conventional. See Fig. 10.

Examples of self-lubricating polymers include fluorinated alkane, e.g., Teflon, fluorinated polyethers, fluorinated polyesters, polyether ketones, e.g., PEEK, nylons, or acetal resins. Examples of self-lubricating polymeric compositions include a resin component and from about 30 wt.% to about 0.5 wt.% of a lubricating system. Resin components useful in the polymeric composition can be selected from polyamides, polyesters, polyphenylene sulfides, polyolefins, polyoxymethylenes, styrene polymers, and polycarbonates. The lubricating system of the present invention can be characterized as containing a lubricating amount, sufficient to reduce friction and wear, of the resin component and can include polytetrafluorethylene, stearates, and calcium carbonates. Many other materials, including solid lubricants and fibers, e.g., graphite, mica, silica, talc, boron nitride and molybdenum sulfide, paraffin waxes, petroleum and synthetic lubricating oils, and other polymers, e.g., polyethylene and polytetrafluorethylene, can be added to the resin component to improve friction properties.

Embodiment No. 12

This invention provides a safety technique to determine when the posts are consumed. Embodiments include incorporating a tracer component, such as an inert chemical, to provide a warning as to the number of wafers capable of being polished by the partially consumed web. In another aspect, a notch or a bar is provided for a mechanical indication. See Fig. 11.

Some indicators are higher than the surrounding, to indicate the end of the CMP process. When the indicator or bar is reached, only a certain amount of height remains. This can be detected by visually inspecting or by physically sensing the height to determine when the heights of the post and wear bar are equal.

Embodiment No. 13

This invention resides in providing a mechanical means, such as a notch, to determine when approaching the end of the abrasive web roll. See Fig. 12. When advancing the web, it is advantageous to know when the end is approaching to avoid running out of roll. A notch is provided which can be detected either mechanically or optically, similar to the dots that flash to indicate to a projectionist in the movie theater that the end of a reel is approaching, or the prink stripe in cash register receipts, preferably, on the web back to avoid impacting the process.

Embodiment No. 14

The invention resides in coding the web throughout its length to enable determining the location of different portions of the web. Bar codes or a number readable with optical character recognition can be used. Little holes can be punched through to provide a detectable pattern. Any type of encoding along the length of the web can be provided and read with an appropriate type of sensor. The inventive concept involves encoding the location along the length of the web. There are at least two benefits. One is real time feedback and any kind of motion control. For example, the length of a moving web is determined with feed back control to activate a command signal to advance the web. A second benefit is that the amount of web advanced can be read. This enables: (1) good tracking of wafers polished to location on web; and (2) determination of the proximity to the end of the web and alarm for an operator to replace the web.

Embodiment No. 15

A thin monolayer, e.g., one millimeter, of diamond is formed on the web posts containing silicon carbide particles, and chemical preconditioned to remove about 500 A° of matrix from the top of the posts to expose the diamonds, as by chemical preconditioning using heat or solvent to selectively remove the matrix.

This embodiment advantageously prolongs the wear rate of the web through the use of superabrasive, a term used in the industry for a very hard material, e.g., diamond, or cubic boronitride. The wear rate of the posts are reduced to the extent that they don't change appreciatively over time, thereby improving CMP uniformity.

Embodiment 16

This invention resides in providing perforations in the sides or end of the web for improved handling. Rolls can be provided with sprockets to engage the perforations.

The present invention is applicable to all types of fixed abrasive articles, including rotating polishing pads that are substantially circular and substantially rectangular polishing sheets. The present invention provides wafer-to-wafer rate stability for CMP and can be employed during various phases of semiconductor device manufacturing. The present invention, therefore, enjoys utility in various industrial applications, particularly in CMP in the semiconductor industry as well as the magnetic recording media industry.

Only the preferred embodiments of the present invention and but a few examples of its versatility are shown and described in the present disclosure. It is to be understood that the present invention is capable of use in various other combinations and environments and is capable of changes and modifications within the scope of the inventive concept as expressed herein.